HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE

Technical Report 206-26

SONAR OPERATOR DETECTION PERFORMANCE AT SEA

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SONAR OPERATOR DETECTION PERFORMANCE AT SEA

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Prepared for

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by

Human Factors Research, Incorporated
Los Angeles, California 90019

April 1964
Contract Nonr 2649(00)
NR 153-199

ABSTRACT

An earlier experiment using training equipment ashore indicated that a significant improvement could be expected in sonar target detection performance by employing bias and gain voltages which differed from those typically employed. This report describes a similar, though briefer, experiment undertaken at sea with an AN/SQS-23A sonar.

In a preliminary experiment, using project personnel as observers, detection performance was determined for several values of bias and gain. In the main experiment detection performance of the ship's eight sonar operators was compared when (1) employing their favored values of bias and gain, and when (2) employing values selected as a result of the preliminary experiment.

It was found that by increasing the gain (actually decreasing the gain voltage 3.3 volts) above that typically selected by operators of an AN/SQS-23A sonar operating at sea, target detection performance with respect to targets generated by the sonar test set was improved by approximately 3 decibels.

This result provides objective evidence for the validity of the frequently made observation that many sonar operators search at a gain level substantially below the optimum.

ACKNOWLEDGEMENTS

This research was made possible by the fine cooperation of the officers and men of the U.S.S. ENGLAND (DLG-22).

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INTRODUCTION

In an earlier experiment (Baker, 1963) concerned with the target detection performance of sonar operators, a comparison was made between performance when the PPI display was at values of bias and gain set by the operators, with that when the display was at experimentally determined optima of bias and gain. Detection performance in the latter condition was markedly superior.

That experiment was performed ashore with an SQS-10 sonar and a UQS-T1B trainer. Since this sonar is now obsolete and since artificially generated reverberations were used, a logical extension was to attempt to confirm the findings at sea. This report describes a similar, though briefer, experiment undertaken at sea with operational equipment.

GENERAL METHOD

The ship made available for this experiment was the U.S.S. ENGLAND, a DLG equipped with an AN/SQS-23A sonar, including test set TS-1222/SQS-23. The experiment was performed at sea while en route to Long Beach, California from Puget Sound, Washington.

The general method was, first, to attempt in a preliminary experiment to determine favorable values of bias and gain for the ship's sonar when in the search mode, and second, in a main study to compare the target detection performance of the ship's sonar operators when employing their own values of bias and gain with that when employing the experimentally determined values. The sonar was in normal operation throughout the experiment with the consequence that the reverberations and other random reflections displayed were the result of actual sonar transmissions. Realistic appearing targets were generated by the test set situated in the sonar equipment room.

METHOD (PRELIMINARY EXPERIMENT)

The first step was to determine a range of bias and gain voltages to be explored. To do this, two VTVMs were mounted at the stack, one to measure CRT bias voltage and the other to measure gain voltage.[1] With the gain turned well down, bias voltage was determined when the circular sweep was at the threshold of visibility and also when the bias was decreased to a point where the display could be described as "extremely bright." These bias values were 43.7 and 41.0 volts, respectively. This range of just 2.7 volts is, in our experience, extremely small; in the earlier experiment (Baker, 1963) for instance, the range required to generate similar display brightnesses, dark and bright, was 7 volts.

The range of gain voltage to be explored was determined with the bias voltage set at a value such that the circular sweep was just visible. Gain voltages were determined for a display on which there were virtually no reverberations present, and also for an "extremely noisy" display, with heavy reverberations. These gain values were 13.3 and 9.0 volts, respectively, a range of 4.3 volts.

From the above measures, three values of bias voltage and three values of gain voltage were selected for experimental purposes. These values were,

Bias voltages: 43.7, 42.5, 41.0 volts
Gain voltages: 13.3, 10.5, 9.0 volts

These three bias voltages and three gain voltages constituted nine experimental conditions and a target visibility threshold was determined for each subject in each condition. Subjects were two experienced HFR personnel.

To determine target visibility thresholds the subject sat in front of the display which was operating in one of the experimental conditions. The experimenter, who was in telephone communication

[1]Details are given in Appendix A.

with the subject from the sonar equipment room, decreased the attenuation of a target reference voltage at the sonar test set in one-decibel steps on successive pings. When the target was detected--it always appeared at 000° and half-range--the subject said "target" and the experimenter noted the decibels of attenuation of the reference voltage. The mean of six such values constituted a target visibility threshold for one subject.

Throughout this preliminary study manual[1] gain control was employed and the 10,000-yard range scale was used. The ship was moving at 16 1/2 knots. (The desired speed for both preliminary and main studies was 15 knots but because of steaming schedule restrictions the number of hours available for sailing at the desired speed was limited and they were consequently saved for the main study.)

RESULTS (PRELIMINARY EXPERIMENT)

The results of the preliminary experiment are shown in Figure 1 for the two subjects combined. Figure 1 shows target visibility thresholds as a function of CRT bias for three gain voltages: the higher the plotted values, the better the performance.

From Figure 1 several facts are apparent. First, at all three bias voltages a moderate gain of 10.5 volts was superior to a low gain of 13.3 volts. Second, while with the gain of 13.3 volts detection performance appears to have been best at the medium bias of 42.5 volts, this was not true with the greater gain (lower gain voltage) used, 10.5 volts. With 10.5 volts of gain performance was virtually identical in the case of the two highest bias voltages and dropped off only when the lowest bias voltage (brightest display) was employed. Finally, bias had a most marked effect on performance when the greatest gain (9.0 volts) was employed: with the dimmest display (a bias of 43.7 volts) performance was virtually as good as that in any other condition, but with less bias (greater brightness), performance deteriorated markedly. In other words, there was an interaction between bias and gain.

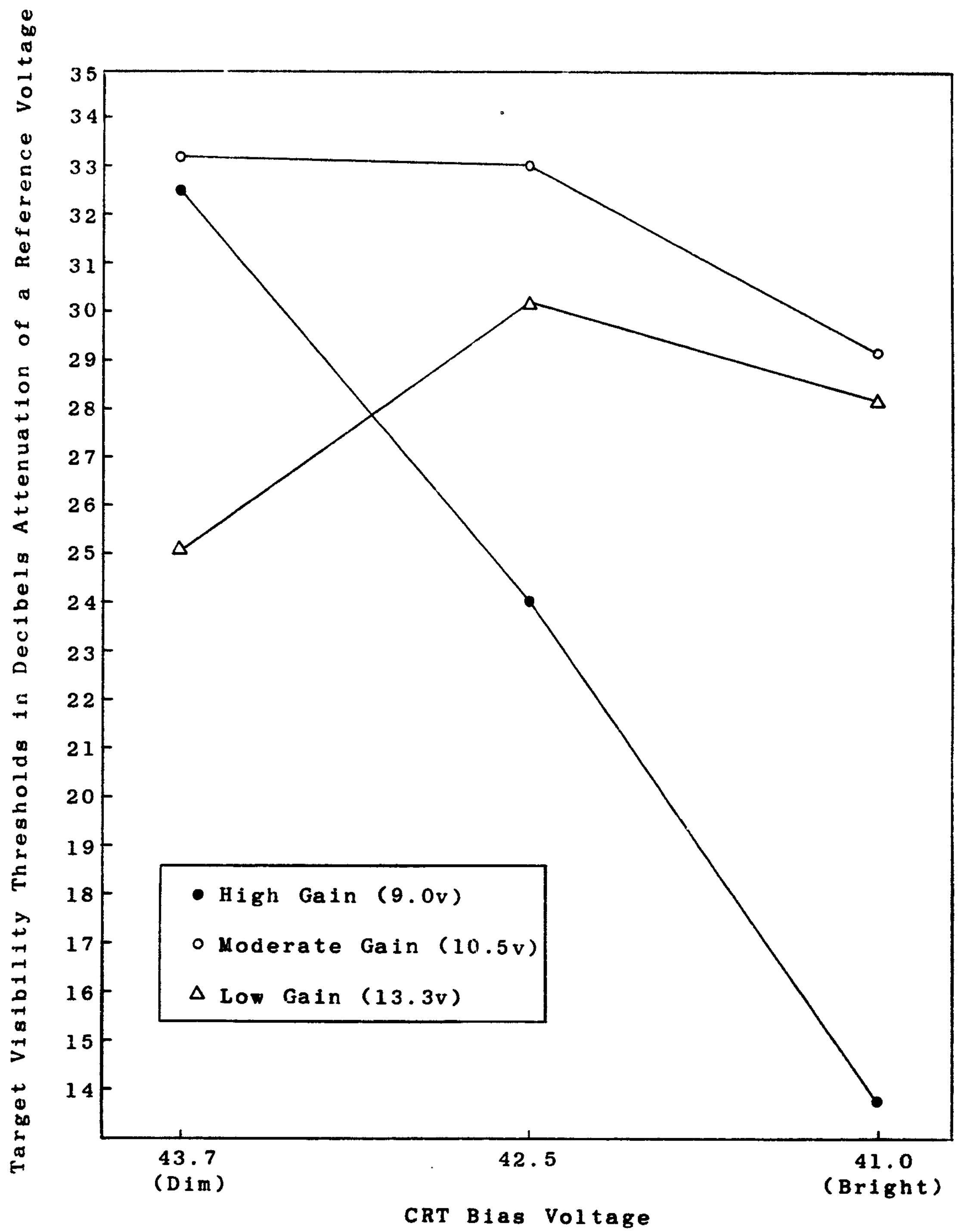

Figure 1. Target visibility thresholds and CRT bias for three levels of gain (N = 2).

DISCUSSION (PRELIMINARY EXPERIMENT)

The data in Figure 1 were obtained to permit the selection of favorable values of bias and gain for use in the main target detection experiment. Of the three gain voltages employed, an intermediate value of 10.5 volts resulted in superior performance, and this was the gain voltage selected for use in the main experiment. At this gain level little difference was found between bias voltages that produced dim or medium bright displays, 43.7 and 42.5, respectively. Consequently for the main study an intermediate bias voltage of 43 volts was arbitrarily selected.

It will be appreciated that in the limited time available a comprehensive study of the effects of bias and gain could not be undertaken. We would have liked to have explored more values of bias, and certainly more values of gain. The difficulties were compounded by the fact that the reverberation pattern occasionally changed in a noticeable fashion (which was not reflected by the B/T pattern), and also by the fact that return from sea clutter, which often persisted for several pings, obscured the area where the experimental target appeared. Finally, it was a perceptually difficult task to detect a near-threshold target when the area surrounding its known location was alive with sea clutter which was, on occasion, extremely bright.

METHOD (MAIN EXPERIMENT)

The main experiment, in which the ship's eight sonar operators acted as subjects, was concerned with the detection of targets which appeared at unknown locations on the display. Ship's speed was 15 knots.

Targets were generated at the 12 different locations shown in Figure 2 and which are designated L, M, and S, for long, medium, and short range, respectively. As a safeguard against the possibility that target locations might be learned, a deliberate attempt was made on the second presentation of a target at any location to vary the location slightly. Thus, with the 10,000-yard range scale, L, M, and S in Figure 2 represent ranges of approximately 9,000, 6,000, and 3,000 yards, but these were varied during the experiment by as much as ± 300 yards. Similarly, while the average azimuths employed were 015, 075, 135, 225, and 315 degrees, they were deliberately varied within ± 10 degrees of these values.

The procedure was as follows. The operator sat in front of the display and an experimenter (E_1) stood slightly behind him. A second experimenter (E_2) was at the test set in the sonar equipment room. All three were on the same telephone circuit. Instructions to the operator, from E_2, were as follows.

> You can see that the display is quite dark. I want you to set the scope intensity and reverberations the way you would if you were going on watch right now to search for targets. Leave the range at 10,000 yards. You'll be using medium pulse and sum brightening. (Pause while this is done.)
>
> Now I'm going to give you some targets to detect, one at a time. I want you to go through your normal search procedure, that is, place your cursor tip on the target and report range and bearing whenever you make a detection. Each target will be very weak to begin with but I'll make it stronger and stronger until you detect it. After you've detected each target, you can have a short rest until I tell you to start searching again. Any questions? Start searching now for the first target.

After the operator had made his bias and gain settings, the voltages on the two VTVMs were recorded by E_1. From a prepared list of targets designated by range and relative bearing, E_2 then generated the first target, below the detectability threshold, and decreased the attenuation in one-decibel steps on successive pings until the operator reported a detection. All operators searched in the conventional manner, using both the visual and audio displays. Using his identical list of target locations and making

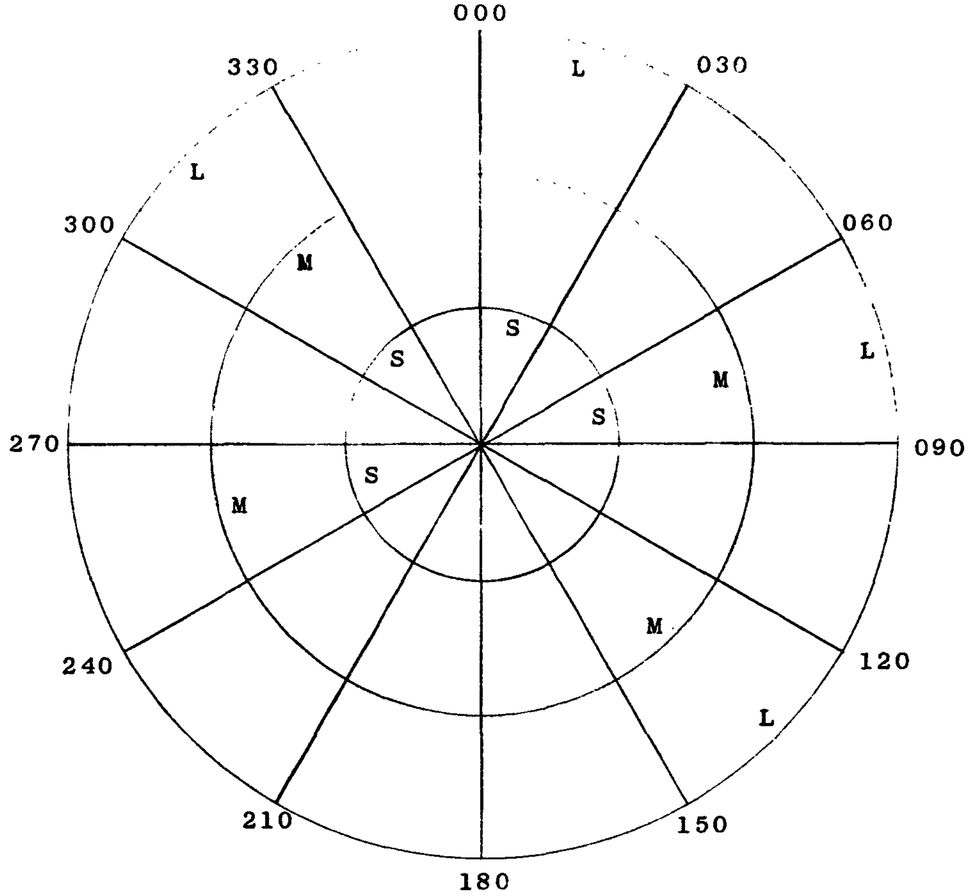

Figure 2. The letters S, M, and L, for short, medium and long range, designate the 12 general target locations employed.

the necessary conversion to true bearing[2], E_1 confirmed the detection for E_2, who then recorded the amount of attenuation for that target and proceeded to generate the next target.

When 12 targets, presented in random order, had been detected further instructions to the operator were as follows.

> We will now change the display before having you search for more targets. (E_1 set the bias to 43 volts and gain to 10.5 volts.)
>
> The display is now somewhat different from the way you had it. You've probably never practiced with a display like this one, but we want you to try it. Now start searching for the first target.

A further 12 targets were generated and the amount of attenuation recorded as each detection was reported.

RESULTS (MAIN EXPERIMENT)

The results of the main experiment are shown in Figure 3. It is apparent that at all three ranges target detection performance was superior when the display was set at experimentally determined voltages of bias and gain to that when set at those voltages selected by the operators. Further, when the experimentally determined voltages were employed, detection performance continued to improve with increasing range, while the voltages selected by the operators resulted in performance at long range which was no different from (or even slightly inferior to) that at medium range. The advantage in detection at 3,000, 6,000, and 9,000 yards of employing the experimentally determined voltages was 2.27, 2.49, and 4.42 decibels, respectively, the average advantage being 3.06 decibels.

The bias and gain voltages selected by the eight operators are shown in Table 1.

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[2] The ship traveled due south a great portion of the time and consequently the usual conversion involved adding 180°. However, occasional slight changes in ship's heading resulted in a slightly different conversion.

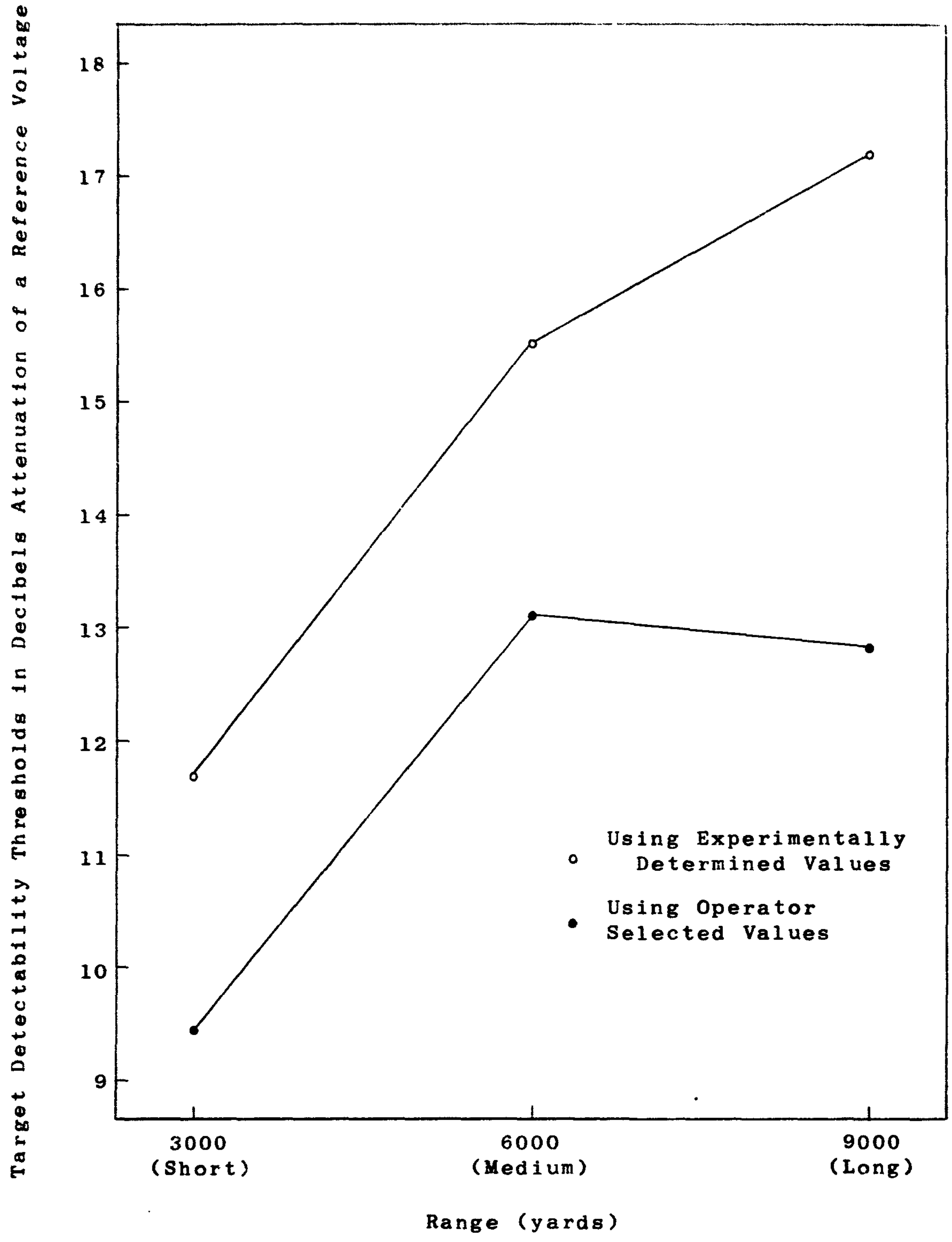

Figure 3. A comparison of target detectability thresholds as a function of range when using experimentally determined values of bias and gain vs. operator selected values (N = 8).

Table 1

Bias and Gain Voltages Set by Eight Sonar Operators

Operator	Bias Voltage	Gain Voltage
1	42.5	12.3
2	44.0	14.0
3	43.0	14.3
4	44.0	14.4
5	42.6	14.7
6	42.0	13.0
7	42.2	13.7
8	42.2	14.0
Average	42.9	13.8

From Table 1, it is apparent that the average bias voltage selected by the operators was not far from that selected from the preliminary experiment for use in the main experiment. However, the average gain voltage chosen was 3.3 volts greater (less gain) than the experimentally determined value of 10.5 volts. In other words, the average advantage of some 3 decibels in target detection performance which was found when employing experimentally determined bias and gain voltages was due to the use of greater (10.5 volts) gain.

DISCUSSION (MAIN EXPERIMENT)

The results of this study indicate that there are gain voltages which differ from those typically employed and which, if used by the operator during sonar search, would significantly enhance his ability to detect targets, particularly targets appearing near the periphery of the display.

While a significant advantage can be expected in target detection performance by properly adjusting the gain voltage, the advantage in the present experiment was less than that observed in the earlier one (Baker, 1963).

Several reasons for this difference can be suggested. First, we have used the term "experimentally determined" rather than "optimum" in reference to the bias and gain voltages selected from the preliminary experiment. Because of the limited time available we were unable to fully explore bias and gain voltages. There may be values of either, or both, which would have resulted in detection performance which was superior to that found in this brief experiment.

Second, the apparent range of usable bias voltages in the AN/SQS-23A studied was extraordinarily limited: it might be that, unlike some other sonars, within this relatively narrow range the bias voltage employed is not a factor which significantly affects detection performance.

A third point is that the data reported here indicate an interaction between bias and gain. While there was a slight suggestion of such an interaction in the earlier experiment (Baker, 1963, Figure 5) the data reported here, Figure 1, show it to be most pronounced. The one precedent we know of with respect to such an interaction was reported by Garner (1946) for the radar case. Garner found that a more positive bias can help compensate for low gain, and a high gain for low bias, but the compensation was never complete. In other words Garner found an optimum gain and an optimum bias for that gain. That this is not typically the case, in radar at least, was pointed out in Figure 3 of the earlier report. The interaction found in the present study suggests that there is an optimum gain voltage for the AN/SQS-23A and possibly an optimum bias voltage for that gain. In addition, it is probable that these optima vary for different sonar conditions (and possibly even among different sonar sets). To determine what these voltages are would entail a considerably more extended period at sea than that available for the experiments reported here.

CONCLUSION

By increasing the gain (actually decreasing the gain voltage by 3.3 volts) above that selected by operators of an AN/SQS-23A sonar operating at sea, target detection performance with respect to targets generated by the sonar test set was improved by 3 decibels.

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Baker, C.H. Improvement in sonar operator detection performance consequent to the use of optimum bias and gain. _Human Factors Research, Inc. tech. Rep._ 1963, No. 206-20 (for the Office of Naval Research).

Garner, W.R. A study of factors affecting operation of the VG remote PPI. _Office of Naval Research, SDC Report_, 1946, No. 166-1-1.

APPENDIX A

Electrical Measurements and Control Settings

A. Gain was determined by the setting of the "master level" control while in the "manual" gain mode of receiver operation. It was monitored at terminal 1A-150 in the control indicator with a Heath IM-13 VTVM. The meter had 11 megohms input resistance. An additional meter, a Triplet 630-NA, was used to monitor the receiver gain line to insure direct control of receiver gain with the master level control in the event of malfunction.

B. Display sweep intensity (bias) was varied with the intensity control in the control indicator. It was monitored at terminal 1E-14 with a Heath IM-13 VTVM.

C. The ship was purposely selected for this research because of the calibration status of the sonar, having just completed tests at Dabob Bay. However, the R.C.G. calibration, deflection amplifier calibrations, CRT focus, sweep zero calibration and test set echo level, range, and bearing calibrations were checked.

D. The following control settings were employed

1. Range scale selector - 10,000 yards.
2. Mode selector - attack.
3. Attenuator - off.
4. Full scale flybac' switch - full scale.
5. Bearing handwheel - operator control.
6. Range handwheel - operator control.
7. Pulse length switch - medium.
8. Xmit sector center - not operable in "search."
9. Xmit sector width - 300°.
10. Video switch - SCD.
11. Sum-diff - sum.
12. Xmit depression - 0°.

13. Rec. depression - 0°.

14. Local audio - operator preference.

15. Xmit freq. dev. - 0.

16. Gyro switch - on.

17. Director switch - search.

18. RDT-autoswitch - RDT

19. Stabilization - on.

20. Sound velocity - 4800'/sec.

21. Own ship speed - 15 kts.

22. Cursor intensity - operator preference.